CHAPTER 3

ESTABLISHING ROUTE PROFILE AND ALIGNMENT SPECIFICATIONS

3-1. Introduction.

a. The procedures outlined in this chapter (along with information on locomotive propulsion force, desired train capacity, propulsion resistances, and train operating requirements) can be used to select the maximum grade and curvature and minimum transitions between grades and reverse curves.

b. Initially, these specifications should be treated only as guidelines, as analyses of route topography may require changes to keep construction costs within acceptable limits. Typically, the information and procedures described in this chapter will be used iteratively with those in chapter 4 until a suitable compromise is reached.

c. In appendix B, a sample problem illustrates the determination of a ruling grade.

d. The specifications listed in this chapter are primarily for main running tracks. Additional profile and alignment specifications for terminal areas are given in chapter 8. Details on field layout of horizontal and vertical curves are given in chapter 7.

3-2. Grades and Grade Resistance.

a. Definition. Railroad grades are designated by the amount of elevation change in 100 feet of length, expressed in percent. The additional force required to move a train, due to the presence of a grade, is known as grade resistance. Grade resistance equals 20 pounds for each ton of train weight and percent of grade. Thus, it takes twice the force to pull a train up a 2% grade as it does a 1% grade. For this reason, the choice of maximum gradient (the rate of elevation change on a particular grade) can have a great effect on operations over a route.

b. Ruling Grade. When a particular grade limits train size (tonnage) and speed over a route, that grade is known as the ruling grade. The ruling grade is not always the steepest grade, as a train's momentum may help carry it over a grade steeper, but shorter, than the ruling grade.

c. Grade Design Categories. Grade design categories for main running tracks are shown in table 3-1.

3-3. Route Profile and Transitions Between Grades.

a. Profile and Grade Length. A route's profile is characterized by the steepness of grades and changes in grade along the route. Train operations are enhanced by avoiding frequent changes between ascending and descending grades (a rolling profile). Route design and construction are often simplified by avoiding frequent changes in grade steepness. Table 3-2 shows recommended minimum grade lengths.

b. Transitions between grades.:

(1) Transitions between grades are made with vertical curves. These transitions are necessary for smooth train operation, but they increase the amount of surveying and staking required and are more difficult to construct than uniform grades.

(2) Design guidance for grade transitions is given in paragraph 7-2b.

3-4. Curvature, Curve Resistance, and Effective Grade.

a. Minimizing Curvature. In general, sharper curves require more maintenance than gradual curves; they experience more rail side wear and gage widening. They also create more propulsion resistance. Thus, long term benefits are gained by minimizing curvature in a route.

b. Curve Design Categories. Table 3-3 shows curve design categories for main running tracks.

c. Combining Curves. When designing a route, changes in direction should be accomplished as uniformly as possible, avoiding a series of curves connected by short tangents. Where the distance between adjacent curves (of the same direction) is less than 300 feet, try to combine the two curves into one long curve of smaller degree (see fig 3-1). Combining closely spaced curves usually provides advantages of less design work, easier construction, and reduced long term track maintenance.

Table 3-1. Grade Design Categories for Main Running Tracks.

0.0 to 0.4%	Light
0.4 to 1.0%	Moderate
1.0 to 2.0%	Steep
1.5%	Suggested Limit for Ruling Grades
2.0 to 3.0%	Very Steep: To be avoided if possible

Table 3-2. Recommended Minimum Grade Lengths.

Maximum Speed	Between Different Ascending or Descending Grades	Between Ascending and Descending Grades
15 MPH or Less	500 Feet	1000 Feet
Above 15 MPH	1000 Feet	1500 Feet

Table 3-3. Curve Design Categories for Main Running Tracks.

Degree of Curve	Design Category
0-3	Gradual.
3-64	Moderate.
4	Preferred limit, especially where speeds will exceed 15 MPH.
.6-8	Sharp.
8	Maximum allowable where speeds may exceed 10 MPH.
10	Maximum allowable where speeds will not exceed 10 MPH.

d. Curve resistance. Curvature adds to propulsion resistance at an average rate of 0.8 pounds for each ton of train weight for each degree of curve. As a one percent grade adds resistance of 20 pounds per ton, a one degree curve is then equivalent (in resistance) to 0.04% grade.

e. Curve Compensation.

(1) When laying out a route, the additional resistance due to curvature must be accounted for in the design. This procedure is known as curve compensation. Compensating a grade for curvature is almost always required for ruling grades, and is recommended for grades in moderate and higher categories. (Curve compensation is sometimes omitted where curves are very short or of gradual degree).

(2) Where curve compensation is needed, grades on curved track will be reduced by the following:

$$G_r = 0.04 \times D \qquad (eq\ 3\text{-}1)$$

G_r = Amount of grade reduction (percent).

D = Degree of curvature (decimal degrees).

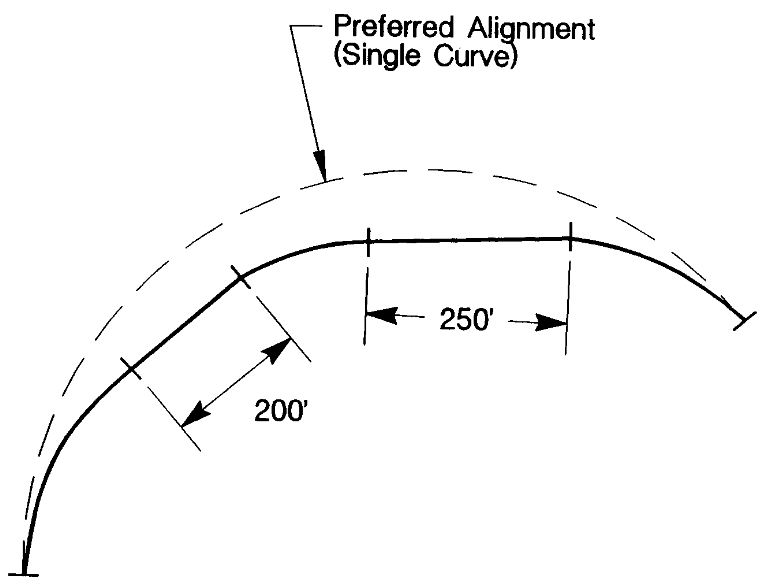

Figure 3-1. Combining Curves.

f. Actual and Effective Grade. Table 3-4 illustrates curve compensation for a 1% grade. As shown, if a train travels around a long curve of 4 degrees on a 1% grade (uncompensated), the combined resistance is equal to a 1.16% grade. To maintain an effective grade (as experienced by the train) of 1%, the actual grade constructed through the 4 degree curve must be limited to 0.84%. Since the actual grade is reduced, compensating for curvature requires a longer track length to reach a given elevation.

Table 3-4. Curve Compensation for a 1% Grade.

Degree of Curve	Uncompensated Grade		Compensated Grade	
	Actual	Effective	Actual	Effective
1	1.00	1.04	0.96	1.00
2	1.00	1.08	0.92	1.00
3	1.00	1.12	0.88	1.00
4	1.00	1.16	0.84	1.00
5	1.00	1.20	0.80	1.00
6	1.00	1.24	0.76	1.00

3-5. Locomotive Tonnage Rating.

a. Definition. The maximum weight of a train that a locomotive is capable of pulling over a route is known as its tonnage rating. Tonnage ratings are affected by many factors, but locomotive tractive effort and ruling gradient are among the most important.

b. Application of the Procedures. The procedures for estimating locomotive tractive effort and tonnage ratings presented below are simplified versions intended for route design purposes. They aren't intended to be used for the actual make-up and dispatching of trains.

c. Tonnage Requirements, Locomotive Assignments, and their Effect on Route Design.

(1) The route must be designed to allow trains of sufficient size to travel over the finished line. Maximum train size is determined primarily from usable locomotive tractive effort and the gradients and curvature along the line.

(2) Designers must verify tonnage requirements with the appropriate transportation officers, as well as understand the general operating plan for routine traffic, training exercises, and mobilization.

(3) On military railroads where government owned and operated engines are used, these engines might handle all routine traffic, but during training exercises or mobilization, a commercial engine may be expected to handle over-the-road operations, while the installation's engine takes care of switching and short moves. Another option, when installations have more than one engine, is to use two engines for maximum tonnage trains when such single train movements are required. Thus, in addition to tonnage requirements, plans for locomotive use must also be known.

d. Determining Locomotive Tractive Effort.

(1) When tractive effort curves are available for the locomotives to be used on the line, tonnage ratings should be based on these curves. Otherwise, tractive effort may be sufficiently estimated with the expressions in table 3-5.

(2) Regardless of locomotive power, usable tractive effort is always limited by wheel-rail adhesion. For design purposes, usable locomotive tractive effort should not exceed W/4, where W is the weight of the locomotive in pounds.

Table 3-5. Estimating Locomotive Tractive Effort.

Speed Range	Tractive Effort
Starting to 10 MPH	TE - 30 x HP
Over 10 MPH	TE - 300 x HP/ V

TE = Tractive Effort (in pounds)
HP = Locomotive Rated Engine Horsepower
V = Traveling Speed (MPH)

e. Determining Tonnage Rating.

(1) While tonnage ratings are commonly given in gross trailing tons (total weight of cars and loads), a convenient practice is to express tonnage ratings as the number of loaded cars a locomotive can pull, using an average or representative car and load for estimating purposes. This can be done using equation 3-2, along with table 3-6 for selecting design car gross weight based on the nominal car carrying capacity.

$$\frac{N_{cars} = \ TE}{[\ 3 + (\ 20\ \bullet\ \%G]\ W_g} \qquad \text{(eq 32)}$$

No $_{cars}$ = Number of cars locomotive can pull.
TE = Usable locomotive tractive effort at desired speed (lbs).
%G = Maximum ascending gradient long enough to contain the whole train (percent).
W = Gross weight of representative car (tons), from table 3-7.

The constants 3 and 20 in equation 3-2 indicate that an average car has a rolling resistance of 3 pounds for each ton of its gross weight and that all equipment requires 20 pounds to lift each ton of weight up each percent of grade. Any curvature on the maximum grade is assumed to be grade compensated, as described in section 3-4.

Table 3-6. Design Gross Car Weights.

Nominal Car Capacity (tons)	70	80	90	100	120	140
Design Gross Weight (tons)	105	115	125	135	160	190

Note: 140-ton cars (nominal capacity) are representative of those carrying 2 M1 Tanks.

(2) For field check, car capacity is normally stenciled on the side of each car in pounds, labeled CAPY. For example, the marking on a 70-ton car would appear as: CAPY 140000.

3-6. Trial Ruling Grade.

a. A trial percentage for the ruling grade can be determined for guiding the first stages of route selection, using equation 3-3. (The 0.15 constant in the equation indicates that the average rolling resistance for each car is equivalent to pulling the car up an additional 0.15% grade).

G = Effective ruling gradient (percent), where the grade length is equal or greater than train length.
TE = Usable locomotive tractive effort (pounds).
W_{ENG} = Weight of Engine(s) (tons).
N_{Cars} = Number of cars in train.
W_g = Average gross weight of a car (tons).

b. All curvature within the limits of the ruling grade should be grade compensated, as described in paragraph 3-4.

c. A ruling grade that is steeper, but shorter, than the calculated ruling grade can also be used as long as the total train resistance of the cars on the grade and the cars off the grade does not exceed usable locomotive tractive force.